(c) *Cloud movement.*—The evidence as to wind movement in the upper air is very scanty, but what there is is interesting. To the north of the storm, at Barnet, the lower clouds were consistently from the northeast or east-northeast, the higher clouds, said to be cirrus, being from the east or south-southeast. "From 2 to 8.30 a constant procession of embryo cumulus passed south of Barnet and seemed to attain development south of that place." Only one important cumulus passed north of Barnet. This agrees with the author's own recollections of the occurrences seen from New Southgate, a little nearer the storm area. At Barnet by 1 p. m. a large pile of cumulus with brilliant protuberances was seen to the south-southeast, beginning to "fan" slightly at the top. It may be noticed that this time agrees with the first fall of hail on the north of the storm.

From Warlingham on the south of the storm magnificent thunderheads were seen at 2 p. m. to the north. This again agrees with the time when hail occurred in the center of the storm. Later, a large anvil-shaped cloud rose up behind the other clouds. From Purley about 3.30 a large cloud pillar was observed 18° east of north and 25° high. Assuming that this was 8 or 9 miles away, the height would be about 3 miles. This rose and merged into the upper cloud.

Within the storm or on its southern margin at New Malden the lower thundercloud moved very slowly from east-northeast, but the "upper cloud" was seen during a lull in the storm to be moving from the south.

### 5. CONCLUSIONS.

In the concluding section of the paper the author discusses the bearings of the facts elucidated on the causes of thunderstorms, and also on the causes responsible for starting storms when conditions are favorable, but he points out that the connection between the facts and the views which he adopts is not very clearly made out. He agrees with Lieut. Douglas that the conditions necessary for summer thunderstorms are produced at some height above the surface,[1] say about 3,000 feet, that they may be started by conditions below that height, and that surface wind phenomena and temperature phenomena, such as the fall of temperature almost simultaneously with the beginning of the storm, are the results and not causes. It would seem probable that a necessary condition for the occurrence of a thunderstorm is that the temperature should decrease at a rate not less than normal, i. e., that the lapse rate should be about 3.5° F. per 1,000 feet for a considerable distance upward, and refers to a suggestion by Lieut. Douglas that this should occur for a height of 6,000 feet from half a mile above the ground. Cirrus, possibly false cirrus, is usually, if not always, present, and when the cumulus reaches a height of 3 to 4 miles its top spreads out. * * *

The author thinks that local surface conditions, such as the relief of the ground, may determine the start of a storm; the high ground of Leith Hill and Hindhead may have given a start to the storm in that district.

The marked belting or banding shown on several of the charts of different phenomena on the 14th suggests the possibility of some form of wave action, and the same idea is supported by the lines of cloud belts during this storm, and also by the maps of rain distribution on thunderstorm days with which readers of British Rainfall are familiar, and which frequently show splashes of rain distributed in lines across the country.[1]

If this is so, an upward movement over the area of the rain field is postulated, and this must be initiated by descent of cooler air on the outside, but this normally takes place above the lowest half mile in the atmosphere. Eventually, of course, some surface air does move inward, giving rise to the cyclonic circulation noticed on the outskirts of the storm, while on the whole calms prevail within the storm area. Later this calm is occasionally broken by violent gusts.

The first of "cyclonic" phase seems fairly clear. There seems, however, to be a second phase in any thunderstorm which remains for an hour or two over the same area. On the one hand the rain field seems to break up into two parallel belts, and on the other the surface wind seems to blow *from* the storm. It seems to be the case also, if we can generalize from two investigations, that the more vigorous of the two belts of rain field into which the storm breaks is on the side from which the wind is naturally coming. On June 14, 1914, the wind on that side, the northern, had a much greater surface velocity. This seems to suggest that the reason for the greater activity has to do with a greater supply of air on that side. As far as any surface observation is concerned this air seems to disappear. The logical inference is that it must be rising. It is possible that the projections of the rain field northwards, e. g., at about 3.45, along neither of the dominant axes may be due to the rising of this air in patches rather than along a continuous front.

As to the breaking up of the storm into two belts the following suggestions have been made. When rain or hail forms, it is said, pressure will first decrease immediately below the point of formation. The rain on falling will reach a terminal velocity. The air through which it passes will be cooled and contract, i. e., become heavier, and pressure will increase. At first these winds will tend to flow inward, and later they will tend to flow out. On this assumption the violent gusts at the surface in the center of the storm during the later stages are due to the descending air. * * * All this goes to show that the rain area was a local high pressure area during the later stages of the storm.

In any case the evidence of the surface winds must be taken into account. As these seem in the later stages to be blowing from the storm it is fair to infer that the pressure is greater along the middle line than on the outskirts.

[1] Douglas, C. K. M., "The lapse-line and its relation to cloud formation," Edinburgh, J. Scot. Meteor. Soc., 17, 1917, pp. 133-147.

[1] Not necessarily from moving storms.—C. F. B.

## WIND STRATIFICATION NEAR A LARGE THUNDERSTORM.

By LESLIE A. WARREN.

[Dated: Weather Bureau Aerological Station, Broken Arrow, Okla., June 25, 1919.]

The accompanying horizontal projection curve of a pilot balloon ascension begun shortly after 3 p. m. on June 20, 1919, at the Broken Arrow Aerological Station (fig. 1) reveals an unusual and very interesting wind condition. The balloon in attaining an altitude of 7,000 meters made three nearly complete reversals in horizontal direction, corresponding to two counter-clockwise whirls which are evident upon the projection. The balloon, after release was carried upward in a light easterly wind until an altitude of 1,500 meters was reached where an abrupt change into a north current occurred. Drifting in this current for 800 meters ascent at an extremely low velocity, the balloon was then carried along in a westerly wind changing to southwest from an altitude of 2,300 meters. The wind direction for the next 1,300 meters ascent as indicated by the balloon's course

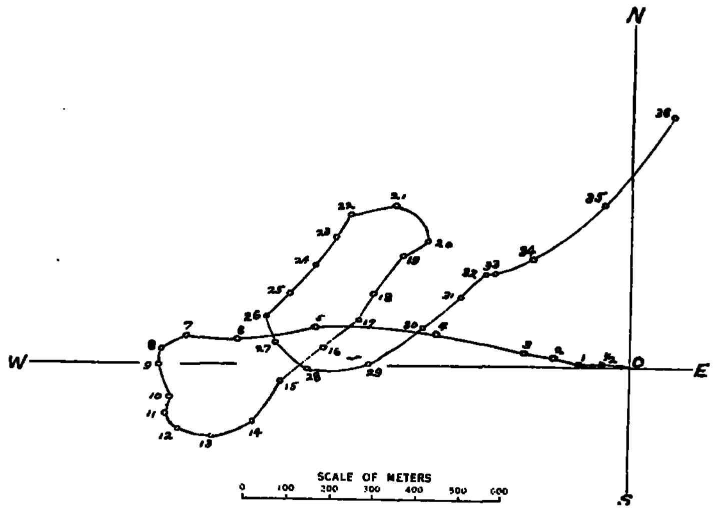


FIG. 1.—Horizontal projection curve showing position of pilot balloon at consecutive minutes.

remained fairly steady from the southwest, then backed to northeast about 400 meters higher. The direction continued from the northeast through an air layer about 1,000 meters thick and again changed through northwest and west to southwest at an altitude of 5,500 meters, and remained fairly steady to the 7,000-meter level where the balloon was lost to sight in a cirrus haze.

Except for short periods the wind velocity as computed was very light. A minimum velocity of 0.6 meter per second at the 2,000-meter level and a maximum of 4.4 meters per second at the highest altitude attained, were found to exist.

This rare atmospheric condition is thought to be closely associated with a thunderstorm which began at 7 a. m. of the same day and continued until a few minutes before the beginning of the balloon run. The sky which had been totally obscured during most of the day with heavy nimbus and cumulo-nimbus clouds began clearing rapidly about 20 minutes before 3 p. m. And in a comparatively short time the lower clouds had disappeared and a variety of upper cloud formations had appeared. The apparent counterclockwise whirling motion of the atmosphere tends to make more pronounced the close connection with the thunderstorm.

The wind blew directly toward the thunderstorm until within an hour of the beginning of the balloon run. The thunderstorm approached from the south-southeast, and as the exceedingly large mass of cumulo-nimbus clouds passed off the wind changed from north-northwest to northeast, east and, finally, when the cloud mass was away toward the northwest horizon it had shifted to the southeast from which it had changed during the first signs of the storm.

Consulting the weather map of 8 a. m. June 20, 1919, it is easily seen by the indicated wind direction at the several stations surrounding Broken Arrow that this station was near the center of a counterclockwise atmospheric circulation. Supposing that this whirl continued with altitude, it seems very probable that the whirls in the balloon's path were also a part of this circulation of greater magnitude.

The inevitable over-and under-running of these converging winds would undoubtedly account for many of the wind differences aloft, while the local thunderstorm winds such as outflow below and above and inflow at intermediate levels would add to the complexity. The counterclockwise direction of the balloon's path being cyclonic also suggests rising air.

Thus it seems that the balloon whirls, the thunderstorm, and the atmospheric circulation indicated on the weather map were in all probability closely interrelated.

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## PRESSURE FLUCTUATIONS DURING A THUNDERSTORM.

Father E. F. Pigot, S. J., of Riverview College Observatory, Sydney, New South Wales, has kindly transmitted to us the accompanying copy (fig. 1) of a record

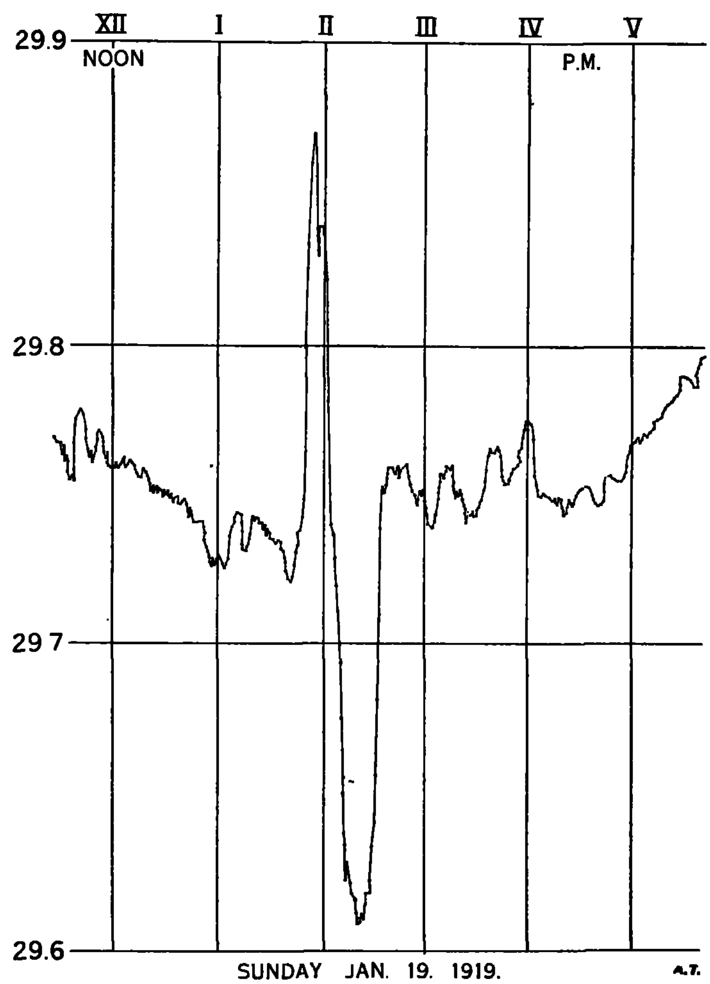


FIG. 1.

from a Murday microbarometer showing the large and rapid fluctuations of atmospheric pressure during the passage of a heavy thunderstorm and squall at Sydney, New South Wales, on Sunday, January 19, 1919. The record is in the form of dots, made at intervals of one minute.—ED.